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THE INFLUENCE OF ARSENIC ON THE BACTERIAL ACTIVITIES OF A SOIL

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SOILS are the earthy material in which plants have their anchorage, and from which they obtain their water and part of their food. They are in reality disintegrated rock, containing, intimately mixed throughout, varying quantities of decaying plant and animal residues. They are derived from the native rocks by a complex process known as weathering. This being the case, we should expect to find within the soil the same substances as were found within the rock from which that soil was formed. Some native rocks carry arsenic in varying quantities; hence, we should expect to find arsenic in some soils, and it has been found to occur to the extent of at least thirteen pounds per acre-foot of soil. It is quite possible if more virgin soils were analyzed arsenic would be found in many of them, and in some in quantities many times as great as here reported.

Furthermore, arsenic is continuously being added to many soils which probably were free from this poison at first. Smelter smoke often contains arsenic, and this finds its way from the air into the soil. Insecticides, such as lead arsenate, Paris green, and many others, are used on many plants and fruits to kill insects. Most of the arsenic of these compounds eventually finds its way into the soil. So we are not surprised to find Headden reporting that he had found in some Colorado soils as much as four hundred and fifty pounds per acre-foot of soil, while Grunner found arsenic to occur in some of the Russian soils to an extent many times this great. An extensive analysis of the sprayed orchard soils of western America showed arsenic to be present in all of those soils and varying from mere traces to five hundred pounds per acre. In some cases it occurred to a depth of three or four feet. But the most interesting fact was that in some of these soils there were even seventeen pounds per acre of water-soluble arsenic. It was not, however, always the case that the greatest quantity of water-soluble arsenic was found in those soils which contained the greatest total quantity of arsenic, for often soils were found which contained only a few pounds per acre-foot, and probably two thirds of it was in a soluble form. So the conclusion has been reached that some virgin and many cultivated soils contain arsenic in large quantities, but the proportion in a soil is no index of the amount which is soluble in water. The latter is probably governed by many factors; *e. g.*, kind of soil, water-soluble salts in it, and form in which the arsenic was applied to the soil.

That the form in which the arsenic is applied governs largely its solubility is shown by an experiment in which one hundred grams of arsenic in the form of lead arsenate were applied to a soil, and to another portion of the same soil were added one hundred grams of arsenic in the form of Paris green. To still another soil was added enough arsenic in the form of zinc arsenite to make one hundred grams of arsenic. These were carefully mixed and allowed to stand for some time, after which an examination was made for soluble arsenic. The analysis revealed the fact that 14 per cent. of the lead arsenate was in the water-soluble form, 30 per cent. of the zinc arsenite was soluble, but over 80 per cent. of the Paris green was soluble.

Arsenic being in the soil, some soluble and some insoluble, it very naturally raises the question as to what effect it has upon the bacteria of the soil, for we know that any factor which influences these must indirectly influence the crop yield from that soil. This being the case, a number of experiments have been carried on to find out how this substance—arsenic—influences the bacterial activities of a soil, and it is the object of this article to examine a few of the facts revealed by this study.

One of the essential elements for crop production, and the one which is usually in the soil in the smallest quantities, is nitrogen. This, unless it be applied to the soil in the form of the costly fertilizer—sodium nitrate—must be prepared for the plant by bacteria. The farmer finds his crop is limited directly by the speed with which these classes of organisms prepare the food for his growing crop. If they are active, other things being favorable, he will get a good crop; but if they do not play their part, everything else being ideal, there is no crop.

Bacteriological examinations of cultivated soils have shown that usually those which are richest contain the greatest number of bacteria. The number in the soil is dependent upon the quantity and character of the food the bacteria find in the soil. If the soil is rich in plant residues, barnyard manure, and the like, many bacteria will be found there, pulling these substances to pieces, liberating gases and acids which act upon insoluble particles of the soil and render them soluble. One class of organisms changes the protein constituents of the soil into ammonia.

This type we speak of as the ammonifiers. One often detects their activity by the odor of ammonia coming from manure heaps. Now how is arsenic going to affect this normal bacterial process of the soil? The question was answered by adding varying quantities and different forms of arsenic to the soil and noting the results. The answer which came showed that the bacteria were not at first poisoned by the arsenic, but their speed of action was increased. The actual results showed that while the untreated soil produced in unit time one hundred parts of ammonia, soil to which sixty pounds of arsenic per acre was applied produced one hundred and three parts of ammonia in the same length of time. And it was not until 2,500 pounds per acre of arsenic was applied to the soil that the ammonia produced was reduced to one half that normally produced. The Paris green, on the other hand, retarded the action of this class of bacteria even in the lowest concentration added, and by the time 600 pounds per acre had been applied the ammonia produced in unit time had been dropped to one half normal. Thus, we find its poisonous action on bacteria is in a direct relationship to its solubility, and an extremely large quantity of lead arsenate would have to be applied to a soil before it would interfere with the ammonification going on in the soil. But we can not yet say that it is not injurious, for this is only one of the classes of bacteria which are working on the soil nitrogen. Most plants can not use nitrogen in the form of ammonia; it must be in the form of nitrates. This transformation is brought about by two distinct types of organisms. One of them feeds upon the ammonia produced and manufactures nitrous acid. Should the transformation close at this point and nitrous acid accumulate in the soil in large quantities, plants would not grow upon it, for this is a poison to plants. But in soils properly cared for only minute quantities of nitrous acid are found. As soon as it is formed another type of organism feeds upon it and manufactures for the growing plant nitric acid. This, when formed, reacts with other constituents of the soil, such as limestone, and it is ready to be taken up by the plant to manufacture nourishing food, beautiful flowers, or fragrant perfumes for the human family. How is arsenic going to act upon these groups of organisms? In order to find this out various quantities of the different kinds of arsenic were applied to the soil and a determination made of its nitrifying powers, with the result that the untreated soil was found to produce one hundred parts of nitrates in unit time, but the same soil to which had been added arsenic in the form of lead arsenate at the rate of 120 pounds per acre produced 178 parts of nitrates. Or, in other words, in place of being injured by the arsenic, the bacteria were nearly twice as active in the presence of this quantity of arsenic as they were in its total absence, and it was not until over 700 pounds of arsenic, in the form of lead arsenate, per acre, had been applied to the soil that the bacterial activity fell back to one hundred. Even when arsenic in the form of lead arsenate was applied at the rate of 3,500 pounds per acre there was 68 per cent. as much ammonia produced as was produced in the untreated soil. The Paris green gave similar results. The untreated soil produced 100 per cent. of nitrates in given time, while similar soil to which arsenic, in the form of Paris green, was added produced, under the same condition, 129 per cent. of nitrates, but when higher concentrations of arsenic in the form of Paris green were added it became toxic, and eventually it stopped all bacterial activity; but the quantity added had to be very large, and it is not likely that sufficient would ever occur under agricultural practise.

So we find that arsenic is not injuring the ammonifying or nitrifying organisms of the soil, but how about the other beneficial bacteria of the soil? What effect has it upon them?

There are seventy-five million pounds of atmospheric nitrogen resting upon every acre of land. But none of the higher plants have the power of taking this directly out of the air. We have, however, certain bacteria which can live in connection with the legumes and assist them to take nitrogen from the air. Then we have another set of nitrogen-gathering organisms within the soil which can live free in the soil and gather nitrogen, and they may, under ideal conditions, gather appreciable quantities of nitrogen. It is quite possible that much of the benefit derived from the summer-fallowing of land is due to the growth of this class of organisms within the soil, storing up nitrogen for future generations of plants. For it has been found that they are more active and found in greater numbers in such a soil. All the work which the farmer puts upon the soil to render it more porous reacts beneficially upon this class of organism, for they not only require atmospheric nitrogen and oxygen, which are absolutely essential to their life activities but these must be obtained from within the soil, for the minute organisms can not live upon the surface of the soil; to them the direct rays of the sun mean death. How is arsenic going to influence this class of organisms which are so beneficial to the soil, but are so much more sensitive to adverse conditions than are the other classes of bacteria? Here we find that arsenic in the form of lead arsenate, zinc arsenite, and arsenic trisulfide, stimulated this class of bacteria, and when arsenic in the form of lead arsenate was applied to the soil at the rate of 500 pounds per acre the nitrogen-fixing organism gathered twice as much nitrogen in unit time as it did in the absence of arsenic. But the Paris green is poisonous to this group of organisms when the minutest quantities are added to the soil, and this is most likely due to the copper and not to the arsenic found within the compound. Hence we find that arsenic stimulates all of the beneficial bacteria. But how does it act? Will it stimulate for a short time and then allow the organism to drop back to its original or a lower level as does alcohol or various stimulants when given to animals? Or will it act as does caffeine—continue to stimulate? From the results on men and horses we might expect the former, for we find that while it is claimed by the arsenic eaters of India and Hungary that the eating of arsenic increases their endurance, and there is considerable evidence to indicate this, it is only for the time being, and if the use be not continued the arsenic eater can not endure the same physical exertion as can others who are not addicted to the drug, Many European horse dealers place small quantities of arsenic in the daily corn given to the horse, as they find it improves the coat of the horse. But if a horse has been dosed for a long time on arsenic it seems necessary to continue the practise; otherwise, the animal rapidly loses his condition.

So we might expect it to be similar with the bacteria, and experiments have shown that, while during the first few weeks the bacterial activity of soils containing small quantities of arsenic is much greater than it is in a similar soil without arsenic, this activity continues to get less until at the end of several weeks it is no greater in soil containing arsenic than in soil containing none. But it is interesting to note that if proper conditions of aeration are maintained it never sinks to a level lower than in untreated soil.

Now why this stimulating influence of arsenic upon soil bacteria? A similar condition has been found to exist when soils are treated with carbon bisulphide, chloroform, or other disinfectants, or even heated, and many theories have been offered to account for it, but probably the most interesting is the idea held by Russel and Hutchinson, who claim that we have within the soil the microscopic plants, bacteria and also microscopic animals, protozoa, and that these minute animals are continually feeding upon the minute plants, with the result that the bacterial plants can not multiply as they could in the absence of these protozoa. Now when a weak solution of an antiseptic is applied to the soil it kills many of the protozoa, and the bacteria, being no longer preyed upon by their natural foe, rapidly multiply, then as the antiseptic evaporates the few remaining protozoa start to multiply and soon are able to keep in check the bacterial flora of the soil. So we should find within the soil one species preying upon another, and possibly some terrific battles are waged by the microscopic forms of life within the soil, just as these are waged by the higher forms of life upon the earth's surface.

It is quite likely that this is one of the ways in which arsenic stimulates the bacterial activities of the soil. It acts more readily upon the protozoa than it does upon the bacteria, for it is found that soils heated just high enough to destroy the protozoa, but low enough to leave the bacteria unharmed, are only slightly stimulated by the arsenic. After the arsenic has been in the soil for some time it may become insoluble or some of it may be changed by moulds into a gas and pass into the air. Then the few protozoa which have not been destroyed by its presence rapidly multiply and soon hold in check the bacteria.

But this is not the only way in which arsenic acts, for some of the bacteria have become free from the soil and also free from all other plant and animal life, and it is found that these are stimulated so they bring about greater changes in the presence of arsenic than they do in its absence. This is due to the action of the arsenic upon these minute specks of living protoplasm, causing them to utilize their food more economically in the presence of arsenic than in its absence. And this we find is similar to the influence of the arsenic upon the cells within the horse.

Other experiments have demonstrated that the addition of arsenic to a soil causes the liberation of the insoluble plant foods of the soil, especially the phosphorus. So we find arsenic by various means stimulating all the bacterial activities of the soil, and these increased activities, as experiments have shown, are reflected in greater crops grown upon the soil. But this increased growth must be looked upon as due to a stimulant and not to the direct nutritive value of the substance added, and soils so treated would wear out more quickly and produce larger crops than would soils not so treated. But it is interesting and important to know that arsenic has to be applied to a soil in enormous quantities before it retards microscopic plant life, and most likely before it retards the growth of higher plants.